California sea lions: Environmental impacts on population status and trend

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The working definition for optimum sustainable population (OSP) is a population size that is at or greater than its maximum net productivity level (MNPL) which is the population size that produces the maximum net productivity (e.g., greatest net change in the population). In a logistic model, MNPL is K/2 where K is the carrying capacity of the population. In a generalized logistic model, an additional exponent $z > 1$ is included which allows MNPL/K to be greater than ½. The default value used for marine mammals has been 0.6. For harbor seals, Jeffries et al (2003) and Brown et al (2005) fitted a generalized logistic model to the counts of pups and non-pups on the beach during pupping. From their analysis, they determined that each population was above MNPL (at OSP) and that MNPL/K was 0.56 and 0.79, respectively.

For California sea lions, only counts of pups are available for a sufficiently long time period (1975-2015) to evaluate population growth and OSP. Berkson and Demaster (1985) determined that pup counts alone could be used to assess a population status relative to OSP but they did not consider situations in which the production of pups varied widely from density independent factors like El Niño events that result in low numbers of births and high mortality of pups. With large changes in pup counts due to increased pup mortality or reduced natality, the number of pups would not immediately reflect the same magnitude change in the total population size and the analysis could be misleading.

As an alternative, we have used population reconstruction. From the number of pups in a year and age-specific survival we can project forward to predict the number of animals in the population at each age over time. Let $N_{f,a,y}$ and $N_{m,a,y}$ be the number of females and males respectively at age a in year y. Assuming a 50:50 sex ratio of pups, then $N_{f,0,y} = N_{m,0,y} = P_y/2$ where P_y is the number of pups in year y. For the remaining formula, we will sometimes only show females with the understanding that the same applies for males. The expected number of sea lions at each age through the ensuing years can be predicted from the sex and age-specific survival rates. For example, the expected number of yearling females is $N_{f,1,y+1} = N_{f,0,y}S_{0,y}$ where $S_{f,0,y}$ is female pup survival in year y. In general, $N_{f,a+1,y+1} = N_{f,a,y}S_{f,a,y}$. The size of the population in year y is simply the sum of all the animals in each age for both sexes alive in that year $N_y = \sum_{a=0}^{A} N_{f,a,y} + \sum_{a=0}^{A} N_{m,a,y}$ where A is the maximum age.

We have used the aerial survey pup counts from Lowry (in prep) for the entire U.S. population during 1975-1977 and 1981-2008 and 2012-2014 and some imputed values for 1978-1980, and 2009-2010 and 2015 from ground counts (NMML unpublished data). From a mark-recapture study of pups branded at San Miguel Island, DeLong et al (in prep) have estimated sex- and age-specific survival rates from 1987-2013. Survival rates for 1975-1986 were extrapolated from a linear mixed effects model fitted to survival estimates for 1987-2013 from the mark-recapture data using sea surface temperature as an environmental covariate and an age-dependent trend over time which was a function of the current abundance relative to carrying capacity, K. Using the counts and survival rates we can predict the number at each age and sex through time except for the non-pups alive in 1975. To include those animals we used the age-distribution equations of Cole(1954) as described by Eberhardt(1985). Let c_a be the proportion at age a. Assuming an instantaneous growth rate r, the porportion at age a is $c_a = e^{-ra} l_a / B_a$ where $l_a = \prod_{a=0}^{a-1} S_a$ and $B_a = \sum_{a=0}^{A} e^{-ra} l_a$. We initially assumed a value of $r = 0.05$ and computed separate age-distributions (c_a) for each sex using the estimated survival rates for 1975. With the pup count in 1975 we estimated the total number of females and males in the population as $N_{f,1975} = P_{1975}/2/c_{f,0}$ and $N_{m,1975} = P_{1975}/2/c_{m,0}$ respectively. Then the number at each age was estimated from the age-distribution formula (e.g., $N_{f,a,1975} = c_{f,a} N_{f,1975}$). With the sex and age-specific numbers in 1975, the pup counts for 1976-2014 and the annual sex- and age-specific survival rates, the numbers at each age for each sex across time were reconstructed.

A generalized logistic difference equation model was fitted to the estimates of total population size from 1975-2014. The generalized logistic has 4 parameters: N_0, the initial population size, R, the maximum rate of increase, K, the carrying capacity, and an exponent z that modifies the location of maximum net productivity level (MNPL) relative to K.

$$N_t = N_{t-1} + N_{t-1} R (1 - N_{t-1}/K)^z - H_{t-1}$$

where H_t are the human caused removals. We allowed R to be a function of SST to account for changing growth rates, including declines due to El Nino events. Carrying capacity ranges from 250-280 thousand sea lions and the abundance at MNPL ranges from 156-182 thousand (Figure 1). The abundance in 2014 is well above MNPL so the population is considered to be at its optimum sustainable level (OSP). El Nino events that raise the SST by 2 degrees can cause a 7% decline in the population.

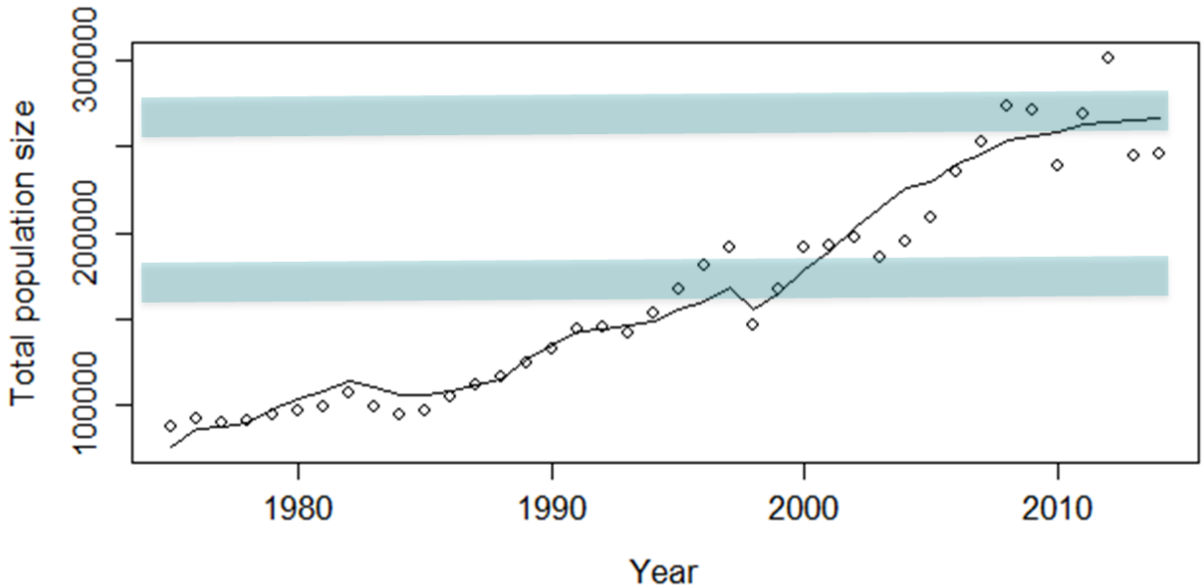

Figure 1. Fitted generalized logistic growth curve to reconstructed sea lion population abundances from 1975-2014. The top blue bar is the range of values for K and the lower blue bar is the range of MNPL from parametric bootstrap replicates.